THE NATURE

AND THE

CONSEQUENCES OF ANOMALIES

OF

REFRACTION

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AN ESSAY

ON

THE NATURE

AND THE

CONSEQUENCES OF ANOMALIES

OF

REFRACTION

BY

F. C. DONDERS, M.D.

LATE PROFESSOR OF PHYSIOLOGY AND OPHTHALMOLOGY IN THE UNIVERSITY OF UTRECHT

(Translated under the supervision of the Kirschbaum School of Languages and Bureau of Translation of Philadelphia.)

REVISED AND EDITED BY

CHARLES A. OLIVER, A.M., M.D. (UNIV. PA.)

ONE OF THE ATTENDING SURGEONS TO THE WILLS' EYE HOSPITAL; ONE OF THE OPHTHALMIC SURGEONS TO THE PHILADELPHIA HOSPITAL, ETC.

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TO

HERMAN SNELLEN, M.D.,

PROFESSOR OF OPHTHALMOLOGY IN THE UNIVERSITY
OF UTRECHT,

THIS ENGLISH TRANSLATION OF THE WORK OF HIS TEACHER
AND PREDECESSOR IS "IN TESTIMONY OF THE
WARMEST FRIENDSHIP AND OF
THE HIGHEST ESTEEM"

Dedicated

BY THE EDITOR.

EDITOR'S PREFACE.

In his duties, the Editor has not attempted in any way to draw a comparison between the Author's and his own thoughts and beliefs on the subjects treated in this volume. It has been his sole desire to give a great man greater honor and to offer such a man's works an increased amount of usefulness. In this spirit, and as a result of this thought, he has given each aphorism exactly as it appeared in the original work, thus enabling him to show to the present ophthalmic world, in spite of innumerable controversies, to what slight extents the fundamental principles laid down by the talented Author in the pages of his almost unique brochure have suffered correction, alteration, and conversion during the thirty progressive years that have followed its publication.

Indeed, it is remarkable, considering the many ways in which the finger of science has in the past three decades since the work was laid away in a comparatively infrequently used language, been guiding medical empiricism by means of skilled observation and laboratory research into

the now fast approaching domain of rational scientific medicine, that this man's work should have so much of the real truth in it, and that his deductions should be so certain of application to newly acquired facts that were unknown at the time he gave his results to the physiologic world. Here, in this branch of medicine —in the study of dioptrics—it may be truly said that the proper application of precise and well-grounded sciences by one who was intimately acquainted with them in their every detail, to the uncertainties of new and never-before-tried work, gave the Author answers that were far ahead of those that were known to the medical men of his day.

To disturb such results, when given in trust, as it were, in a posthumous publication, would be desecration. To give the original conceptions of such monumental and beneficial labor, has been a task of veneration and love.

CHARLES A. OLIVER.

PHILADELPHIA, U. S. A., 1899.

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ABBREVIATIONS.

The following abbreviations are adopted in this work:

E, ... Emmetropia.
M, . . . Myopia.
H, . . . Hypermetropia.
Hm, . . " , Manifest.
Hl, . . . " , Latent.
Ht, . . . " , Total.
As, . . . Astigmatism.
Pr, . . . Presbyopia.
p, ... Punctum *proximum* (nearest point of distinct vision).
r, ... Punctum *remotissimum* (farthest point of distinct vision).
P, ... Distance from p to k': In M $= \frac{1}{P}$ diopter.
R, ... Distance from r to k': In M $= \frac{1}{R}$ diopter.
∞, . . . Infinity.
A, ... Absolute range of accommodation $= \frac{1}{A}$ diopter.
A_1, . . . Relative range of accommodation.
A_2, . . . Binocular " " "
p_0, . . . Radius of curvature of cornea in the visual line.
p_1, . . . Relative nearest point.
p_2, . . . Binocular " "
r_1, . . . Relative farthest point.
r_2, . . . Binocular " "
P_1, . . . Distance from p_1 to k'.
P_2, . . . " " p_2 " k''.
R_1, . . . " " r_1 " k'.
R_2, . . . " " r_2 " k''.
c, ... Point of convergence of visual lines.
k', . . . Anterior nodal point.
k'', . . . Posterior " "
φ', . . . Anterior focal point.
φ'', . . . Posterior " "
l, ... Distance of focal point of a glass lens.
l', ... " " " " " an auxiliary lens of the eye.
$>$, . . . Greater than.
$<$, . . . Less than.
R–P, . . Region of accommodation.
$\frac{1}{P} - \frac{1}{R}$, . . Amplitude of "

A SUMMARY OF THE NATURE OF ANOMALIES OF REFRACTION AND THEIR CONSEQUENCES.

In various places[1] I have written on the changes that are found in the refraction of the eye, with their symptoms and consequences. These writings contain a portion of the results of a series of examinations, extending over many thousands of eyes, that were commenced six years ago, and have been continued with the collaboration of several of my students.

This study gave the subject a wider scope and, at the same time, by bringing into view the connection between cause and effect, rendered the knowledge of the subject-matter more thorough and its general review much easier. In fact, everything pertaining to anomalies of refraction can, at the present time, be united into an easily understood system.

Of that system, a summary is hereby offered to the reader. Examination will show that it not only contains what has been previously said on the subject, but that it sums up in

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[1] See Bibliography.

advance that which will, in the future, find a more extended and more comprehensive consideration. I hope, therefore, that it may not be unwelcome as a guide to some, as an introduction for further study to others, and as a general review to those who may have read and heard of the subject before.

1. EMMETROPIA AND AMETROPIA.

I. Eyes are distinguished into *emmetropic* and *ametropic* ones. In emmetropia, E[1], the posterior focal point, φ'', of the dioptric system, in a condition of accommodative rest, lies exactly within the retina; in ametropia, φ'' lies either in front of the retina (myopia, M), or is situated behind it (hypermetropia, H).

II. E, therefore, has its most *remote point of distinct vision* r situated at ∞, M at a finite distance in front of the retina, and H at a finite distance behind the retina. The distance from the eye (more exactly that from the anterior nodal point k′) to r is R. In M, R is positive, in H it is negative, and in E it is infinite.

The *nearest point of distinct vision* is p; its distance to k′ is P. The range of accommodation may be expressed in the number of

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[1] See List of Abbreviations following List of Contents.

diopters[1] of the lens, which, during relaxation of the muscle of accommodation and under the conditions stated in Paragraph IX, is required to throw a sharp and a clear image on the retina. The range of accommodation is designated $\frac{1}{P} - \frac{1}{R} = \frac{1}{A}$.

III. The point r is to be determined by parallel visual lines—*i. e.*, by estimating the artificial lenses which are required to see luminous points or fine streaks distinctly at a practically infinite distance. To determine the point p, fine threads, or very small luminous points, which are to be brought nearer and nearer *to the naked eye* until their images become indistinct, are to be used as test-objects. The determination should be made during the greatest amount of convergence of the visual lines that is obtainable; so that consequently, in cases of H, and frequently in those of E, it becomes necessary to do this by means of convex lenses, the distances of the points obtained being reduced in accordance with the method of procedure.

IV. The measurement of the radius of curvature, p_0, of two hundred corneæ of eyes that were partly emmetropic and partly markedly

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[1] Vide Paragraph X.

ametropic, by means of Helmholtz's ophthalmometer, has shown that the radius of corneal curvature in the line of vision in both conditions is nearly the same.

The average condition found was:

		Males.	*Females.*
Emmetropia	$p_0 =$	7.785 mm.;	7.719 mm.:
Myopia	$p_0 =$	7.874 " ;	7.867 " :
Hypermetropia	$p_0 =$	7.96 " ;	7.767 " .

V. In the myopic eye, the crystalline lens lies relatively deeper, and therefore the distance of the focal point of the dioptric system of such an eye is correspondingly somewhat greater. That the distance of the focal point of the crystalline lens itself should be smaller has not as yet been made apparent. In the hypermetropic eye, the crystalline lens lies closer to the cornea, and, consequently, the distance of the focal point of the dioptric system of this form of eye is somewhat shorter.

VI. From Paragraphs IV and V, the conclusion follows, *per exclusionem*, that the axis of vision in the myopic eye is the longer, and that in the hypermetropic eye it is the shorter. This has been directly proved, *a*, by determining the actual shape of the eyeball during life, which is at times made possible by having the subject direct the visual line as far outward as possi-

ble; *b*, by measurements made after death in numerous cases of M, and in some cases of H; *c*, by determination of the focal distance of the cornea (estimated from its radius of curvature p_0) of an eye that had had its crystalline lens removed (aphakia), and of that of the artificial lens that was necessary to cause the focal point to fall on the retina,—and this for eyes in which the ametropia, previous to the extraction of the crystalline lens, could have been determined. It is possible, however, that H is sometimes also caused, partly, by a greater focal distance of a flatter crystalline lens.

VII. Through disease alone, the cornea becomes the cause of M; sometimes also of H. Usually, however, its refraction is then at the same time very irregular. In all the following observations, these relatively rare cases of M and H are excluded.

VIII. The individual differences of emmetropic eyes are so slight that it becomes wholly warrantable in taking, after the example of Listing, a schematic eye as the basis for most calculations. In M and H, in which only the length of the axis of vision deviates essentially, the same position of the cardinal points may be admitted.

IX. The degree of H and M is expressed by the amount of refractive power of an artificial lens that is required for correction—that is, to cause the focal point to fall on the retina; or, in other words, to allow the subject to see clearly at an infinite distance. This artificial lens is supposed to be infinitely thin, to stand in the air, and to coincide with k′.

X. The degree of refractive power of an artificial lens is expressed by a definite number of diopters, which is equal to $\frac{1}{\text{distance of the focal point}}$, this distance being estimated in meters. Artificial lenses of plus five diopters' and of minus four diopters' strengths are equivalent to one-fifth of a meter of positive and to one-fourth of a meter of negative distance of focal point.

M = 7.00 signifies a M, in which an artificial lens of seven diopters' strength, and H = 3.50, a H, in which an artificial lens of three and a half diopters' strength is required for correction under the conditions that are noted in Paragraph IX.

XI. About the fiftieth year of age, E gradually makes place for H. Even at the greatest age, however, the acquired H rarely reaches more than one and three-quarters diopters. This is not dependent upon any increasing flat-

tening of the cornea whose radius of curvature rather slightly decreases in aged persons. I have found personally—

In 79 men	. . . .		on an average p_0	= 7.858;
" 20	" under 20 years of age	" "	" "	= 7.932;
" 51	" " 40	" " "	" " " "	= 7.882;
" 28	" over 40	" " "	" " " "	= 7.819;
" 11	" " 60	" " "	" " " "	= 7.809;
" 38 women,	. . . .		" " " "	= 7.798;
" 6	" under 20 years of age	" "	" "	= 7.720;
" 22	" " 40	" " "	" " " "	= 7.799;
" 16	" over 40	" " "	" " " "	= 7.799;
" 2	" " 60	" " "	" " " "	= 7.607.

An increase of the focal distance of the crystalline lens, partly as a consequence of flattening, and partly as the result of hardening with an *increasing* refractive coefficient of the *outer* layers, combined, in very old age, with a shortening of the axis of vision, are to be considered as the causes of acquired H.

XII. M is often hereditary; almost always either in reality or as disposition that is inborn. It increases during the years of development, and, notwithstanding the subsequently increasing distance of the focal point of the crystalline lens (XI), it remains progressive when it exists in a high degree (seven diopters or more) all through life. As such, and also in still lower degrees, it is a disease of the eye that is based upon an increasing morbid expansion of the

ocular membranes, coupled with ophthalmoscopically noticeable atrophy, and is often associated with inflammatory signs that are visible in the bottom of the eye; a condition involving various kinds of disturbances that are more or less necessary.

XIII. M occurs in all grades from zero (the emmetropic eye) to twenty-eight diopters. Grades of seven, nine, twelve, and even of fourteen diopters are not unusual. All distinctions between high and low degrees are arbitrary. In zero, or emmetropia, the axis of vision has a length of twenty-two to twenty-three millimeters; in M of twenty-eight diopters it has a length of about thirty-one millimeters. In high degrees of M, as proved by ophthalmoscopic examination, M is present in a higher degree for direct vision (that is, in the yellow spot), than it is for indirect vision; the expansion of the ocular membranes being the greatest at the posterior pole of the eye.

XIV. H is usually hereditary; then it is always congenital. It increases slightly, especially after the fiftieth year of life, at which age, in case that E originally existed, H begins to develop (compare Paragraph XI). The lower grades occur the most frequently; grades of six diopters are already very rare; while those

of nine and twelve diopters or higher are only found by the way of exception.

XV. In the first place, H is to be separated into *manifest* (Hm) and *latent* (Hl). Only in Hm can the subject see more clearly at a distance with positive lenses; in Hl such lenses are rejected. In Hl, H is suppressed in consequence of an inherent exertion of accommodation which is controlled by habit and can not be arbitrarily nullified.

XVI. The greater $\frac{1}{A}$ is, the higher are the degrees of H that are rendered latent. Moderate degrees are also in measure made manifest, not only permanently so in consequence of a decrease of $\frac{1}{A}$ (with the advance of years), but also temporarily, even in youth, through fatigue following exertion.

XVII. Paralysis of accommodation, temporarily caused by instillations of sulphate of atropine (strength, 1 : 120—that is, one part of the drug to one hundred and twenty parts of distilled water), renders H entirely manifest after one or two hours' time. If $\frac{1}{A}$ should be very great, Hm may, through the cycloplegic action of the atropine, rise from zero to four and a half diopters, and even to six diopters; from

two and a quarter to seven diopters, etc. In E and in M, paralysis of accommodation causes the refraction to diminish barely one-half of a diopter in amount.

XVIII. Hm is further subdivided into *absolute*, in which, notwithstanding the strongest effort of accommodation, φ'' lies behind the retina; into *relative*, in which a sharply recognized point p' is more greatly removed from the eye than the point of convergence of the visual line C; into *facultative*, in which, although the condition may be suppressed by accommodation, yet weak positive lenses are not rejected for distant vision. With the decrease of A, H, which is facultative in youth, soon becomes relative, and subsequently absolute.

XIX. H was observed and correctly characterized by Ware in 1813. Later, it remained unmentioned until 1854, when it was imperfectly described by Ruete, this being followed by the better explanations of Stellwag von Carion, and von Graefe. Based upon the results of the author's examinations, it has been shown that low and moderate degrees of H are very common; that they prevail more frequently than M; that they are sometimes entirely latent; and that they occasionally, even in the latent form, are the underlying cause of two

important anomalies which thus far have not been well understood, *convergent squint* and *asthenopia* or *hebetude* (fatigue produced by exertion in gazing at objects that are situated close to the eye).

XX. The reason why H, although generally prevailing, remained so long unrecognized, seems to be found in the fact that in *very high* degrees of H small objects—for instance, type of an average size (partly because of a more rapid increase of the visual angle than of the circles of dispersion (von Graefe) and partly on account of a gradual reduction of the size of the pupil)—can be seen better near the eye than at some distance from it, thus causing the condition to be regarded as M with weakness of sight. Moreover, the minor degrees of H are latent in youth, and when exposed in later life, are confounded with presbyopia.

2. AMPLITUDE OF ACCOMMODATION (ABSOLUTE, RELATIVE, AND BINOCULAR) IN EMMETROPIA AND AMETROPIA.

XXI. The faculty of accommodation being dependent upon the crystalline lens growing more convex, was assumed on good grounds by Young. This was demonstrated by Langenbeck, and especially by Cramer, directly for

the anterior surface of the lens from the changes of the images of reflection. Later, these, as well as those for the posterior surface of the lens (in a slighter degree), were proved by Helmholtz, who made further measurements and found the results so uniform and certain that he concluded that the ordinary limits of accommodation could approximatively be explained therefrom.

XXII. An alteration in the shape of the cornea does not take place in accommodation. The theory of elongation of the visual axis was long ago refuted by Thomas Young. It appears, therefore, that the act of accommodation rests *exclusively* on changes that take place in the shape of the crystalline lens. Knapp, who in four eyes found alterations in the shape of the crystalline lens, carefully measured them, and proved that they corresponded tolerably well with the A as determined at the same time according to my methods of visual tests.

XXIII. Formerly, a certain degree of accommodation was assumed in cases in which there was an absence of the crystalline lens (aphakia). I have shown, even in youthful subjects, that not the slightest trace of accommodation remains in this condition. In efforts

for accommodation, connected with increased convergence, made exclusively by the inward rotation of one (covered) eye with a narrowing of the pupils of both eyes, a remote bright point, sharply seen through the requisite lens, retained as perfectly its form as it did when looked at with parallel visual lines, notwithstanding that lenses of $+0.125$ D. strength (obtained by a combination of $+0.75$ D. with -0.625 D.—$=\frac{5}{8}$—or inverted) were sufficient to produce a distinct change of form in the crystalline lens.

Herein lies a positive proof that accommodation depends wholly upon changes in the shape of the crystalline lens.

XXIV. $A = P - R$ (compare Paragraph III) signifies the dioptric power of a positive lens which the eye adds to itself by the act of accommodation. This manner of expressing the amplitude of accommodation is in conformity with the actual change that may be supposed to be taking place by the addition of an auxiliary positive meniscus lens to the anterior surface of the crystalline lens.

XXV. This helping lens l' (l' denoting the distance of the focal point) is, however, not exactly equal to $A = P - R$. From the powers of P and R and of l' (computed from the form of

the crystalline lens of the same person, measured during life, and during accommodation for distant and near vision), it has been shown that in the emmetropic eye $\frac{1}{A} : \frac{1}{l'} = \frac{1}{9} : \frac{1}{10}$.

XXVI. It is further found that l' : A slightly differs in M and H. If the supposition be made that the cardinal points have the same situation, it will be realized that an equal change of form of the crystalline lens represents a slightly greater amplitude of accommodation in the myopic eye, and a somewhat smaller one in the hypermetropic eye than that which is present in the emmetropic organ. (In high grades of H, and—as might be expected, by reason of the diseased stretching of the ocular tunics—in high degrees of M, much smaller values are generally given to both l' and A.)

XXVII. A difference in the value of A in M and H of moderate degrees is, however, not shown empirically. It is possible that the value of l' in myopia is in reality smaller.

XXVIII. When P and R are modified by the employment of convex or concave lenses, they are designated as P_0 and R_0. By the use of negative lenses, P_0 and R_0 become more greatly removed than P and R; while by the employment of positive ones they become less removed.

Further, P_0—R_0 is not equivalent to P—R, but becomes increased by the use of concave lenses, and diminished by the employment of convex lenses, these results being the more pronounced the further the lenses are made to stand in front of the eye.

Through magnifying lenses A is more greatly diminished. How little remains during the employment of microscopes, spy-glasses, and telescopes, can be readily determined when the following ratios are obtained: A.

F′, the focal distance of the objective;
F″, the focal distance of the ocular;
x, the distance from the objective to the ocular; and
y, the distance from the ocular to *k*′.

XXIX. The various grades of M and of H in their relation to A are represented graphically by the table on the following page.

The numbers 18 to 0 (Fig. 1) give the distances of the points of distinct vision that are situated in front of *k*′, while those below 0, running from 0 to 9, designate similar distances that are positioned behind *k*′. Each of the lines *a*, *b*, *c*, and *d*, uniting *p* and *r*, shows the amplitudes of accommodation, these being proportional to the lengths of the lines themselves. The line *a* represents E, with A = 9; the line *b*, likewise, shows E, with A = 1.50 (presbyopia); the line *c* designates M = 3, with A =

$12—3 = 9$; and the line *d*, on the contrary, exhibits $H = 3$, with $A = 3 + 3 = 6$.

XXX. The amplitude of accommodation A is the *absolute* one. For any amount of positive convergence of the visual lines, p_1 and r_1, together with P_1 and R_1, as their distances to *k'*, are employed. The symbols $A_1 = P_1 — R_1$ are

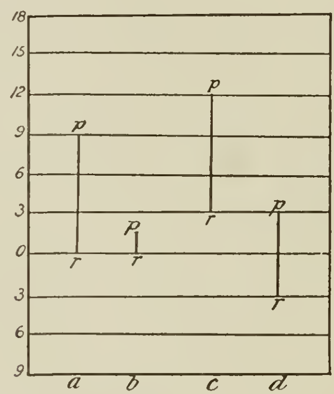

FIG. 1.

used for the *relative* amplitudes of accommodation *in any given convergence.* The farthest and the nearest points seen simultaneously by both eyes are characterized as p_2 and r_2; their distances to *k'*, as P_2 and R_2 respectively; and the binocular amplitude of accommodation, as $P_2 —R_2 = A_2$.

XXXI. Fig. 2 represents the positions of the

nearest points, p_1, p_2, and p, and of the farthest ones r, r_1, and r_2 at differing divergences, as studied in an emmetropic eye of good accommodative power in an intelligent individual of fifteen years of age (compare Paragraph XXXIV). The numeration on the table has the same meaning as that given above. The degree-marks placed

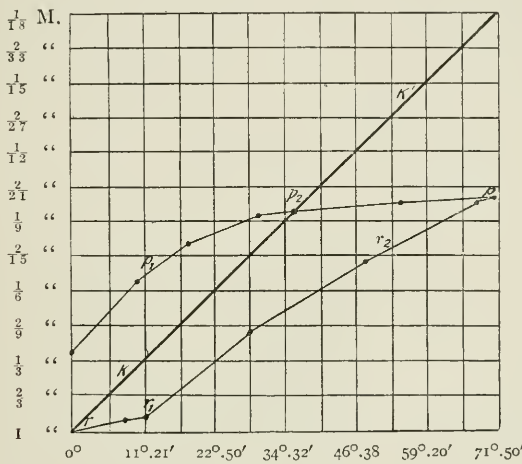

FIG. 2.

below the figure, represent the angles made at the point of convergence of the visual lines that have been calculated for a distance of sixty-four and a half millimeters between the parallel visual lines of the two eyes. On the diagonal K K′, the vertical lines, expressing the degrees of convergence, intersect the horizontal ones

which represent the distances in fractions of one meter each that correspond with these degrees. The signification of the remaining letters in the figure can be understood by reference to the previous paragraphs.

XXXII. With the knowledge of the meaning of the lines p_1, p_2, and p, and r, r_1, and r_2, in their relation to the degrees of convergence, everything that relates to accommodation becomes understandable. Thus, from Fig. 2 the following may be inferred:

E
$A = 9.75$ diopters.
$A_2 = 9.25$ "
A_1—for $11°21' = 6.00$ diopters, etc.

XXXIII. Figure 2, moreover, teaches that, as far as p_2, a portion of A lies above and another part is situated below K K′. The former is the positive, and the latter is the negative portion, of the relative amplitude of accommodation. Accommodative action can only be continued for a distance in which the positive part of A is not too small in comparison with the negative portion.

XXXIV. To find the lines p_1, p_2, and p and r, r_1, and r_2, it becomes necessary, in addition to obtaining p and r, to determine p_0 and r_0 with

various convex and concave lenses ; care being taken to take note of every corresponding degree of convergence. Further, by reduction of p_0 and r_0, according to the focal distances of the lenses used, and their distances from the eye, it is obligatory to compute p_1 and r_1 in exact correspondence with the different degrees of convergence. The black dots in figures 2 and 3 show the points that have been gotten in this manner.

XXXV. For the determination of these measurements, I employed an optometer, in which the lenses, which were laterally separated from one another by a distance that was equal to that of the parallel visual axes of the two eyes, were placed at 0″.5 from k'. These lenses were moved in grooves which were so constructed as to describe arcs from the turning points of the eyes, in such a way that the distances of the lenses to k' always remained the same, and, at every angle of convergence, the visual axes coincided with the axes of the lenses that were employed.

XXXVI. The variation in the forms of the lines p_1, p_2, and p, and r, r_1, and r_2 in M and in H (Fig. 3, M and H) is remarkable.

It is apparent that with slight convergence, myopes can not accommodate so much by far,

and that hypermetropes can and must accommodate more greatly than emmetropes (compare Fig. 2). With hypermetropes, only after ciliary paralysis has been obtained (vide Paragraph XVII), can the point r be determined as r_t,—the farthest point of total H, as indicated

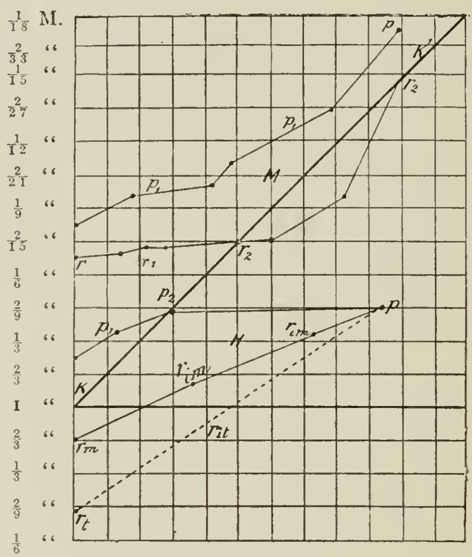

FIG. 3.

in figure 3. The points r (r_{1m} in the figure) are situated higher than would be the case if H were not to so great a degree latent, being therefore noted in the figure as r_{im} (that is, r_1 in manifest H). The latent portion, with parallel visual lines, is shown by the vertical distance

between r_m and r_t, which is here equal to 3.50 D., while the total hypermetropia, H or Ht, is equivalent to 4.75 D.

XXXVII. Dissimilarity in the conformation of the lines is the consequence of practice. Myopes habituate themselves to accommodate but feebly with slight degrees of convergence, whereas hypermetropes, under similar circumstances, accommodate very forcibly. By the continual employment of correctional spectacles, the shapes of the lines more nearly approach those of emmetropes: in a like manner, even a brief use of spectacles will have a similar influence.

XXXVIII. The form of the lines p_1, p_2, and p, and r, r_1 and r_2, in ametropia, proves that the neutralization of the ametropic condition by concave or convex lenses, has not rendered the eye similar to an emmetropic organ.

XXXIX. This makes manifest why each ametropic case should not be at once entirely neutralized. In order to understand this clearly, r in ametropia (Fig. 3) should be brought to ∞ and the lines reduced in accordance. However, the condition gotten, does not accurately represent that which is really obtained by the neutrali-

zation of the ametropia (compare Paragraph XXXVIII).

3. VISUAL ACUTENESS AND PROJECTION IN EMMETROPIA AND AMETROPIA.

XL. The acuteness of vision, V, of different individuals is obtained and compared by determining the smallest angle under which they are able to recognize objects of known form in an illumination of average intensity. Square capital letters may serve as objects (vide Snellen's test-type), by which control in reference to certainty of recognition is vouchsafed by the fact that they must be named. With a normal eye, the subject is able to recognize such letters under an angle of five minutes' opening (SNELLEN). Some subjects have the ability to see the test-objects under a smaller angle.

Snellen's test-letters are numbered in accordance with the distance D, at which they can be properly seen under an angle of five minutes. If, therefore, the distance *d*, at which the letters can be recognized, is ascertained, the degree of visual acuteness will be equivalent to $V = \frac{d}{D}$. In normal acuity of vision, it will be found that $d = D$ and $V = I$.

XLI. V in M is *often* imperfect. In $M > 6$ diopters, it is nearly always so unless the re-

fractive condition is congenital and the subject is quite young. In M>7 diopters, imperfect visual acuity is the *rule*, while in M>9 diopters, it will always be found to be below normal.

XLII. On account of the greater distance from k″ to the retina in M, retinal images for equal angles under which objects can be seen, are larger. In opposition, as it were, the retina, in consequence of stretching, is greater in extent, and, therefore, contains a fewer number of percipient elements in any given area of surface. With a complete compensation of both of these factors, the projected retinal images would retain an equal size, and V in each case remain the same. The fact that V in high degrees of M is generally lessened in the position of the visual line, is—not considering diseased alterations—explained by the stretching of the ocular membranes, which has been ascertained anatomically to be relatively greater in the region of the yellow spot.

XLIII. In the estimation of V with concave lenses that neutralize the myopic condition, it will be found that the visual acuity is lower than normal. This is so because the second nodal point k″ (including the artificial lens in the dioptric system of the eye) is situated closer to the retina, causing the retinal images to become

smaller. The closer the correcting lenses are placed to k″, the more readily do they neutralize the myopia, the further removed is k″ from the retinal plane, and, in consequence, the less influence do they exert on V.

XLIV. In minor degrees of H that are overcome by constant exercise of the power of accommodation, V is not infrequently normal. In addition, by reason of the actually shorter distance of k″ to the retina, the retinal images are not so large as those that are found in an emmetropic eye. The retina of H, however, offers a smaller surface, so that, notwithstanding the fact that the total number of percipient elements be equally great, they must necessarily stand much closer to one another. Whether such be really the case, especially in the region of the fovea centralis, is well worthy of further examination.

XLV. In the higher grades of H, V is not seldom found to be imperfect. In the highest degrees, it is usually the case. Various causes for these results are brought into play by the existent conditions : *a*, the retinal images are smaller ; *b*, there often exists an abnormal symmetry of the refracting surfaces of the eye ; and *c*, in the highest grades of H, the entire eye is

imperfectly developed, the nerve taking share in this faulty development.

XLVI. When in H, clear images are obtained on the retinal plane, not by undue exertion of the power of accommodation, but through the employment of bi-convex lenses placed in front of the eye, then such retinal images (because k″ is moved forward) are probably as large or possibly larger than those that are found in the emmetropic eye: consequently, V increases. In moderate degrees, V corrected in a similar manner, is sometimes >1; in other cases, it $= 1$. In high degrees, however, V remains often <1, this generally resulting from the causes that are mentioned in Paragraph XLV, under *b* and *c*.

XLVII. In young subjects who have been successfully operated on for congenital cataract, and as a result, have a refraction of about H = 14.5 to 12 diopters, H, when properly corrected by a bi-convex lens, often gives $V>1$. The causes of this are the increased size of the retinal image, and the forward displacement of *k″* by the substitution of an artificial lens that is placed in front of the cornea for the crystalline lens which was situated behind the cornea.

XLVIII. In the correction of H, the focal dis-

tance of the lens that is used must be as many inches (millimeters) greater as the lens is removed from the eye. As a result of this, the images of the retina become successively larger and larger in size ; an act that may be compared to that of the working of a Galilean telescope, in which the objective corresponds with the convex lens before the eye, and the concave lens of the ocular, in association with the eye, may be considered to belong to a hypermetropic eye. As calculation teaches, the magnification is quite marked. In cases of H = 14.5 diopters, a lens of 12 diopters' strength, held at one and a half centimeters' distance in front of the eye, produces a lineal magnification (relatively to an emmetropic eye before operation) of 1.322 times; while a lens of 2.25 diopters' strength, held at ten centimeters' distance in front of the eye, gives a magnification of more than seven times the true size.

In higher degrees of H without aphakia, similar use may be made of a relatively weak convex lens as a Galilean telescope.

XLIX. Lenses that magnify or minify, alter the relation between the dimension of the image of the retina and the movement of the head that is required to survey an object which is situated in the line of vision without moving the eyeball. Therefore, should the head be

moved under such circumstances, it will appear as if all objects that are seen magnified are advancing toward the eyes, and that all objects that are apparently diminished in size are receding from the eyes. Such, however, is not the case when the eyes are moved, as the disturbed relationship is practically compensated for by the incorrect direction in which an object that is seen obliquely through the lens is supposed to lie.

As a rule, the various visual directions are obtained in measure by coetaneous movements of the head, and in part by rotatory motions of the eyeball. In such cases, the apparent movement of objects takes place, though only to a slight degree, by the employment of magnifying or minifying lenses.

L. Magnifying lenses have the effect that measurements made with them on a surface that is perpendicular to the visual line are projected larger when *one eye* is used than without a lens; whereas, on the contrary, estimations of depth (differences of distance) made under similar circumstances are projected smaller. Diminishing lenses give results that are the opposite. The key thereto is essentially this: *Equiform* objects or surfaces, some angles of which are commonly known as right angles, produce, when placed at similar distances and

under equal inclination, *dissimilar* perspective retinal images that are the direct results of differences of size. Consequently, uniform retinal images, with a difference in size, cause them to be projected as unlike objects. Lenses change merely the size, and not the form, of retinal images. Therefore, their employment gives rise to a projection of other forms; that is, such, by which, retinal images that are of relative size, would be produced. A study of their construction teaches that these are less deep the larger the retinal image becomes, and *vice versâ.*

LI. Likewise, the *stereoscopic parallax for two eyes* is decreased by magnifying lenses, and is increased by diminishing ones. The explanation thereof lies enclosed in this: that from slightly remote objects, the angle under which a surface shows itself perpendicular to the visual axis is inversely proportionate *to the distance;* while, on the contrary, the parallactic angle for the two eyes is about proportionate *to the squares of the distances.*

LII. In high grades of myopia the retina is stretched. The retinal image is therefore projected smaller than it was before the distention took place. With a disproportionately great amount of stretching at the posterior pole of

the eye, an object that is seen directly is projected smaller than it was before the stretching; in fact, it is projected smaller than it is in emmetropia (compare Paragraph XLII). Notwithstanding this, in fixing an object, its size is exactly determined and its boundaries are precisely indicated with the finger. In directing the line of vision successively upon the object's diametrically opposed boundaries, the modified connection between the quantity of the necessary contraction of the muscles and the projected size of the images is not indicated by any apparent movement of the object.

Thus, a point of the retina is, in consequence of a slowly progressive displacement by stretching, projected outwardly in a direction which is unlike that of the original. If the line of projection for a selfsame percipient element of the retina can, in spite of displacement, change so as to retain its connection with other means of perception, it is admissible to assume that the direction is not original, but has been brought into existence by an association with some other means of perception.

LIII. In a similar manner, the projection of the entire visual field, equally with all its points, can, under abnormal conditions, be modified. With any fixed state of equilibrium of the muscles of the eye, an object that is seen directly,

apparently lies straight before the eye. If the position is changed while the subject believes that the same equilibrium has remained,—in paralysis, for instance, or after section of the internal or the external rectus muscle, etc.,—he will still project that which is seen centrally, directly in front of his eyes, although the object is situated to one side; the visual field then being improperly projected. Studied in connection with the other eye, it will be found that double images are one of the consequences thereof—they being homonymous in character when the eye has turned towards the nasal side, and heteronymous in type when it has deviated towards the temporal side. If, however, the deviated eye is constantly used alternately with its fellow,—which occurs especially in deviations toward the temporal side,—it learns to localize and duly distinguish its impressions from those of the other eye. The projection is then made with much exactness, and thus, the situation of the two objects, which have their respective images placed in the foveæ centrales of the yellow spots are shown as quite different. Both yellow spots are thus no longer projected towards the same points in space. In like manner, with such deviation, with or without the employment of weak prismatic glasses, homonymous double images are seen of an object whose retinal images fall to the outer side of

the fovea centralis of the right as well as of the left eye. The reverse condition may appear after a long-continued or a congenital deviation of one eye to the nasal side.

LIV. Herein lies the proof that, in abnormal position of the visual axes, each eye by itself can learn to project its field of vision in the correct direction, and that, therefore, the ordinary projection of the two fields of vision upon each other can also be learned as a consequence of the subject seeking for corresponding retinal images for the two keenly percipient yellow spots. Accordingly, through projection of their impressions, with slight allowances to be made for one another, other retinal points also acquire the value of very closely corresponding points, which signification, not being dependent on any fundamental anatomic condition, they may also lose again.

4. LINE OF DIRECTION, CENTER OF ROTATION, AND MOVEMENTS OF THE EYE IN EMMETROPIA AND IN AMETROPIA.

LV. The long axis (*g a*, Fig. 4) of the corneal ellipsoid cuts the cornea almost exactly at its middle (Helmholtz, Knapp). The same applies to ametropic eyes (*g a*, of Fig. 5, showing a myopic eye, and *g a* of Fig. 6, showing a

hypermetropic one). The visual line $l\,l'$ is the line of direction which, extending through the nodal point, unites the fixed point of the object

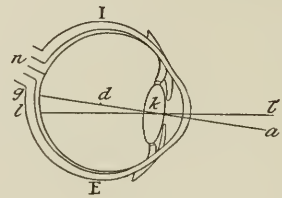

FIG. 4.

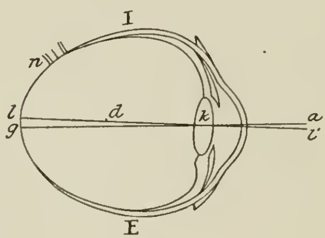

FIG. 5.

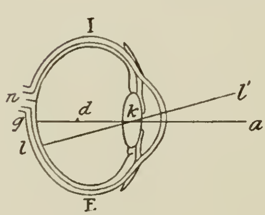

FIG. 6.

with its retinal image, which—as examination with the ophthalmoscope has taught me—lies in the fovea centralis of the yellow spot.

The visual line cuts the cornea at the nasal

side and generally slightly above the middle (SENFF, HELMHOLTZ, KNAPP). If the refracting surfaces are centered, as is almost always the case, the axis of the cornea practically becomes at the same time the visual axis, and is crossed at *k* by the visual line under an angle that is shown by *l k g*. This angle is designated by the symbol *a*.

LVI. The angle *a* differs in the emmetropic and in the ametropic eye. In fifteen emmetropic eyes, we (DONDERS and DOIJER) found 7° as the maximum and 3° 5′ as the minimum, with an average of 5° .082′; in twelve hypermetropic eyes, 9° was the maximum, 6° was the minimum, and 7° 55′ was the average; in ten myopic eyes, the maximum equalled 5° 25′ and the minimum equalled 1° 5′ (that is, 1° 5′ to the temporal side of the axis of the cornea, as can be seen in Figure 5), with an average of 2°.

LVII. The result of the various values of the angle *a* is that, with parallel visual lines, the corneal axes of hypermetropes diverge more than those of emmetropes, while those of myopes, on the contrary, diverge less, or even converge. With similarly directed visual lines, therefore, myopes show an apparent convergent squint, while hypermetropes exhibit an evident divergent strabismus.

LVIII. The cause of the various values of the angle *a* is, as regards myopia, to be found in the stretching of all of the ocular membranes, *mostly* at the outer posterior portion of the eyeball, so that the yellow spot is moved towards the nasal side. In hypermetropia, the greater value of the angle *a* is due in measure to the shorter distance between k'' and the retina, and in part to a congenitally more external situation of the yellow spot.

LIX. The angle *a* was obtained by determining the *angle* formed between the visual line and the axis of an ophthalmometer that was *required* to have a flame placed in this axis, reflected exactly in the middle of the cornea; the reflecting image being situated in the middle, when each of its double images corresponded precisely with the border of the opposite double image.

LX. In the said position of the double images, the designated angle of the ophthalmometer-plates simultaneously indicated the half-breadth of the cornea, or rather its half-chord; the situation of the turning point behind this chord being determined by calculating how great the angles of rotation (equal on both sides) must be in order to cause the extremities of the chord to alternately come together

with the same point in space. The probable fault in this calculation amounted to less than one per cent.

LXI. To the distance between the corneal base and the turning point was added two and six-tenths millimeters as the height of the segment of the cornea. In this manner was found column "b" of the following table:

		Position of the Turning Point:				
	a Length of the optic axis.	b behind the cornea.	c in front of the posterior surface of the sclerotic.	d Percentage proportion.	e behind the middle of the optic axis.	f Angle between the axis of cornea and the line of vision.
	mm.	mm.	mm.		mm.	
E	23.53	13.54 :	9.99 =	57.32 : 42.48	1.77	5°.082
M	25.55	14.52 :	11.03 =	56.83 : 43.17	1.75	2°
H	22.10	13.22 :	8.88 =	59.8 : 40.2	2.17	7°.55

Column "a" was computed from the ametropia, in which it was supposed that the cardinal points corresponded with those of the schematic eye.

LXII. The table demonstrates that the turning point lies rather considerably behind the

middle of the visual axis with which it was formerly considered to almost meet. For the hypermetropic eye, this result is particularly true, though perhaps the crystalline lens in such an eye is less convex than it is in the emmetropic organ, in which the computed visual axis (column "a") would be too short, and consequently, the turning point of the eye would lie relatively more anteriorly.

LXIII. The position found for the turning point of the eye is advantageous for the movements of the organ. The nearer the point of rotation is situated to the posterior extremity of the visual axis, the less are the movements restricted by the optic nerve. As a rule, the larger eyeball is generally the cause of the restrained movement of the highly myopic eye; at least the distance between the turning point of the eye and the laterally displaced optic nerve is relatively not greatly increased.

5. ACUTENESS OF VISION AND AMPLITUDE OF ACCOMMODATION, MODIFIED BY AGE.

LXIV. Figure 7, herewith given, has been copied from an article by Dr. Vroesom de Haan, entitled "Investigations on the Influence of Age on Acuteness of Vision," which was published at Utrecht in 1862. The studies

were made on two hundred and eighty-one subjects, one or both of whose eyes were normal, without any opacities, and free from disturbing astigmatism. $M > 0.75$ diopters, and manifest H of 0.5 diopters, except in advanced age when $H = 1.25$ diopters was still allowed,

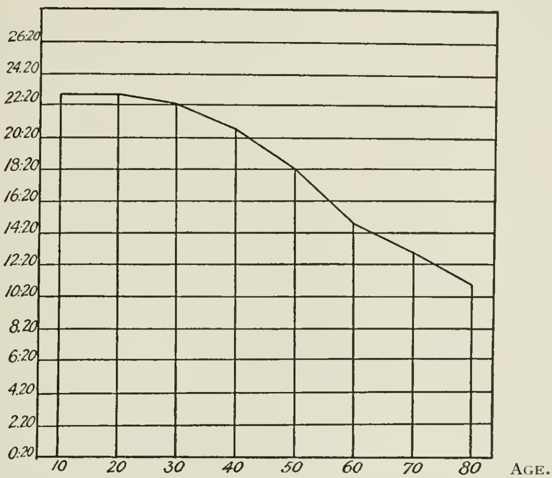

FIG. 7.

were excluded. During the examination, care was taken to correct all ametropia.

LXV. In the figure, the age is given in the abscissas. The ordinates show V, which is expressed by the number of feet, d, at which $D = XX$, is recognized. In his investigation, DE HAAN required only the recognition of the letters

U, A, C, and L. As a result, the equation that he found for V was too large. An examination has taught us that on account of this error, a reduction of one-sixth was necessary; which decrease has been introduced in the figure.

LXVI. The figure teaches that in the emmetropic eye, up to about the age of twenty-seven years, V remains almost unchanged. From this age it slowly decreases until it falls below $V = 0.5$ in advanced life.

LXVII. It further appears that to the age of forty-two years, V is, as a rule, >1. There exists, however, quite pronounced individual differences. In cases in which $V = 1$, no cause can be properly assumed as to the presence of any anomaly; this is the signification of what has been adopted by SNELLEN as $V = 1$. DE HAAN found as his maximum that $V = 1.7$.

LXVIII. The studies were all made under adequate illumination. A series of personal tests, made in each instance by DE HAAN, taught him, however, that on account of differences in illumination under which the examinations were made on various days, there appeared oscillations of $V = 22.5 : 20$, and $V = 19.5 : 20$. These variations were, nevertheless, fairly equally distributed over all ages. Conse-

quently, the line of curvature practically underwent but slight change when all of the examinations were noted as being made during equal degrees of illumination.

LXIX. The cause of lessening acuteness of vision increasing with age must be looked for in the ocular media, as well as in the optic nerve.

LXX. The remarkable clearness with which the *fundus oculi* of young subjects can be seen ophthalmoscopically, confirms the belief that the transparency and the uniformity of structure of the ocular media decrease in advancing age. The crystalline lens reflects a greater amount of light, its tint grows more yellow, and by oblique illumination, the lines of separation of its sectors become more distinct. Irregular astigmatism increases. Monocular polyopia, with imperfect accommodation, in spite of the ever-decreasing pupillary area, becomes more pronounced and more disturbing. The vitreous humor grows more turbid and becomes richer in membranes, corpuscles, and filaments, which, as microscopic examinations and entoptic studies have taught me, are the causes for so-called *mouches volantes*. In these changes, the cornea is the least affected, particularly, at all events, in its middle zone.

LXXI. Among the most prominent alterations seen in the eye-ground of advanced age, are maculated thickenings of the membrana vitrea of the chorioid—knots, as it were, that penetrate into the retina, appearing as protuberances which displace and disturb areas of its outer percipient layer.

LXXII. In high degrees of myopia, acuteness of vision, especially, diminishes much more quickly during advancing age than it does in E. In $M = 9$ or 12 diopters, V at the age of sixty years is usually $< 1/3$.

LXXIII. The cause thereof is, increasing atrophy of the ocular membranes through stretching; this often being coupled with a chronic, low-grade inflammation combined with a slight translucency of vitreous humor. These conditions may be seen with the ophthalmoscope.

LXXIV. As a rule, the amount of atrophy is in direct relation with the degree of M, though in equivalent grades of M it is found to be proportionately most marked in older subjects.

LXXV. In H, the decrease of V which is dependent upon increase of years, pursues a similar course to that which is seen in E.

LXXVI. The amplitude of accommodation, I : A, diminishes even somewhat in early life (from the tenth year or before), and decreases quite regularly so as to about = O at the age of sixty or seventy years. In addition, in the

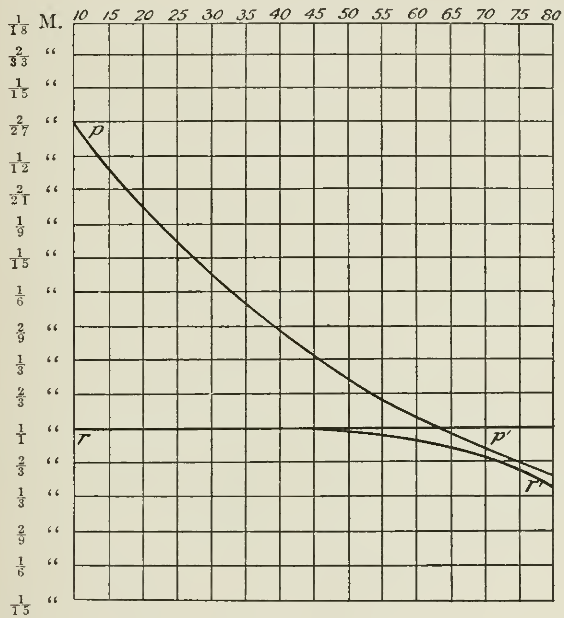

FIG. 8.

emmetropic eye, there is coetaneously formed a slight degree of H. Figure 8, herewith given, illustrates this quite well. $p\,p'$ is the line of curvature of the nearest points, and $r\,r'$ is that of the farthest points, expressive of the function-

ing power of the age (from ten to eighty years). After the sixty-fifth year of age, the determinations of p become less accurate, this being so on account of a lessening of V and by reason of the small diffusion circles that are associated with a narrow pupil.

LXXVII. The cause of the early decrease of $\frac{1}{A}$ while the muscular mechanism of accommodation is still undoubtedly undisturbed, is to be sought in the early increasing density of the crystalline lens, whereby its capacity for change of form is decreased. At a greater age, there is superadded to this an actual diminution of the anatomical constituents of the muscular mechanism.

LXXVIII. The decrease of $\frac{1}{A}$ in E gives rise to presbyopia, Pr. The point at which Pr commences is merely empirical. Especially fine near-work can not be done properly during the use of artificial light in the evening when $P_2 > 22$ cm. With $P_2 > 22$ cm. I have therefore proposed to let Pr commence. This happens in cases of E almost without exception between the years of forty and forty-two. We find the degree of Pr to be $4.5 - \frac{1}{P_2}$.

LXXIX. As Pr advances, the lines p_1, p_2 and p, and r, r_1, and r_2, in cases of E, increasingly

assume the shape which is primarily characteristic of H. Figure 9, exhibiting the accommodation of a forty-three-year-old subject, furnishes the proof thereof. (Compare this with figure 2 in Paragraph XXXVI.)

LXXX. In M, the decrease of $\frac{1}{A}$ pursues

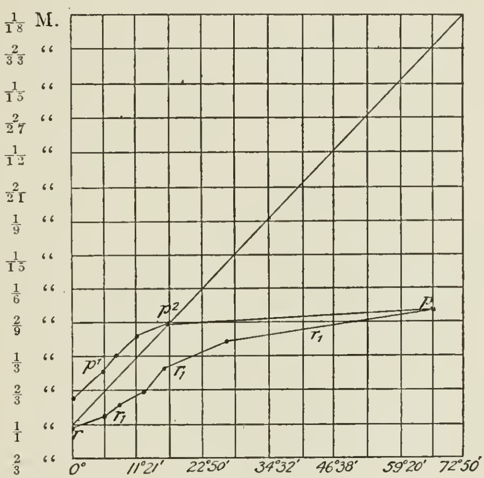

Fig. 9.

almost a similar course to that which is seen in E. Solely in very high degrees, $\frac{1}{A}$ decreases more quickly; otherwise the progress of p is altered by the variation to which r, and consequently M, are subjected.

During the years of development, M is, without exception, progressional, the rule being that

this is the more pronounced the higher is the grade of the M. High degrees of M remain progressive for long periods of time, while the highest grades of the condition are continually advancing.

LXXXI. From the results of a great number of examinations continued over a period of many years, and in accordance with a comparative study of the spectacle lenses that have been employed for many years past, and those that are still used, I have projected the following schemas:

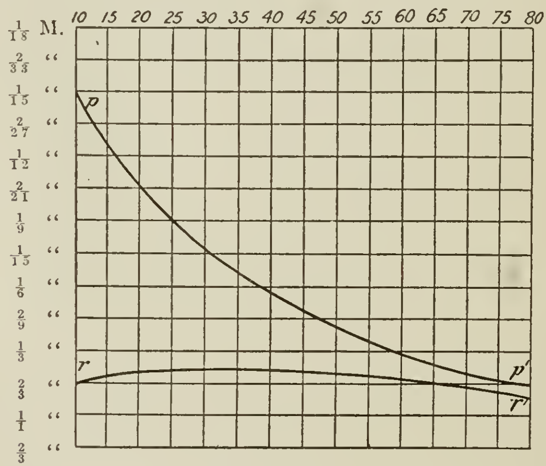

FIG. 10.

Figure 10 represents the course of M as found in a slight and almost stationary degree of the condition.

Figure 11 illustrates the directions that are assumed in a high-grade, temporarily progressive M.

Figure 12 shows the course that is found in a very high, permanently progressive degree.

LXXXII. From this, it can be seen that it is

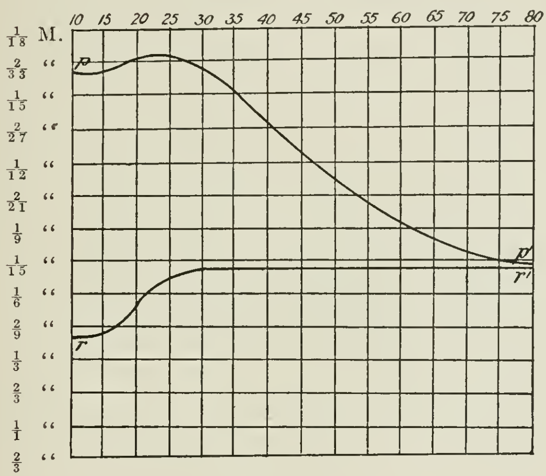

FIG. 11.

an error to suppose that M, as a rule, lessens with an increase of years. The cause of this incorrect opinion is twofold. In the first place, p actually recedes from the eye, and this which was considered as a lessening of M, would only take place if r were to withdraw from the organ. Secondly, the pupil grows smaller, and conse-

quently, on account of smaller circles of diffusion, the subject can often see better at a distance during advanced age, in spite of a slightly increased M.

LXXXIII. Pr is not excluded by minor grades

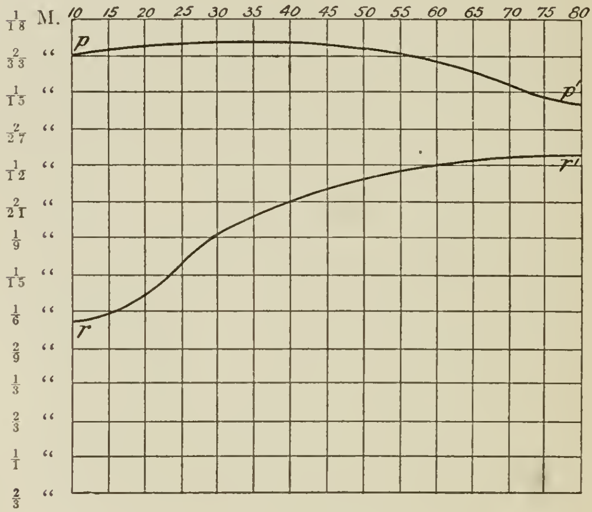

FIG. 12.

of M. It is said to be in existence the moment that P is > 22 cm. In cases in which M = 1.5 diopters with A = 1.5 diopters' strength, *p* is situated at thirty-three centimeters so that Pr = 4.5 diopters — 3 diopters = 1.50 diopters.

LXXXIV. The accompanying diagram (fig-

ure 13) exhibits approximately the course that accommodation, as an attribute of age takes in H. The dotted line r_t r'_t gives the progress of the total H, while r_m r'_m illustrates that of the manifest.

It is apparent that H, which is entirely latent at the outset, becomes increasingly manifest

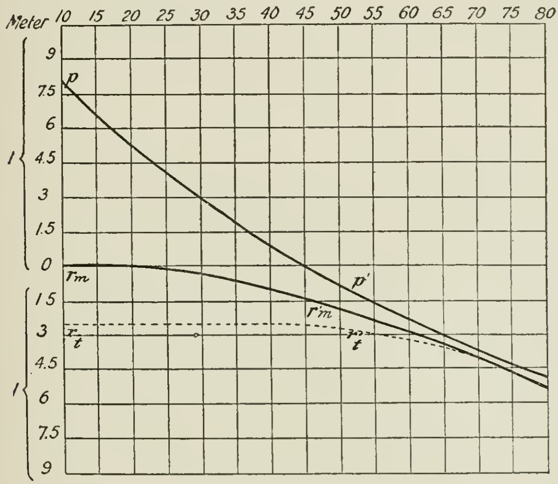

FIG. 13.

until by reason of increasing H, it is finally rendered wholly manifest.

LXXXV. Numerous observations have made it probable that eyes which towards the age of full growth have become emmetropic, have had, in earlier life-time, a minor degree of hyper-

metropia. This is in conformance with the observation that M constantly augments during the years of development.

LXXXVI. Difficulties with regard to seeing at close range arise sooner with H than they do with E. This, however, is not Pr, but is asthenopia. Pr is involved therewith, when, through neutralization of H by the use of an artificial convex lens, P has become $>$ 22 cm.

LXXXVII. The lessening of the amplitude of accommodation, with the increase of age, takes place with great regularity. Favorable exceptions do not exist here. Well may $\frac{1}{A}$ lessen too rapidly by reason of illness, but out of many thousands of cases examined, I have never seen any unusual continuance. He who, in his forty-eighth year, under definitely determined conditions, does not need spectacles, is, without suspecting it, more or less myopic (sees distant objects more clearly through slightly concave lenses). An unusual degree of V may permit the possibility of a postponement for one or two years at the most. He who, though possessing $V = 1$, needs spectacles for reading, writing, etc., before his forty-fifth year, is generally more or less hypermetropic (sees clearly at a distance through slightly convex lenses).

6. CONSEQUENCES OF M AND OF H.

LXXXVIII. The results of a high grade of M are:

(*a*) Diminution of V, which especially becomes more marked with increase of years (compare Paragraphs LXXII, LXXIII, and LXXIV);

(*b*) Restrained movement of the eyeball with absolute or relative insufficiency (insufficient action) of the internal straight eye-muscles;

(*c*) Divergent strabismus.

LXXXIX. Easily mobile emmetropic eyes can cause the visual lines to intersect on the centre of the plane of the forehead at less than 5.50 centimeters from the eye, within an angle of 80° or 70°. If the point of intersection, c, lies farther away than seven centimeters from the turning point of the eye, corresponding to an angle of convergence of about 51°, then, in a general way it may be assumed that there is an insufficiency of the internal straight eye-muscles.

XC. In M, even when ocular motion is unrestrained, relative insufficiency is to be supposed, the moment that it is found that r_2 is situated closer to the eye than c. This occurs the more quickly since the position of the line of vision in relation to the corneal axis, requires

a stronger convergence of the axis of the cornea so as to produce a proper convergence of the visual lines at a definite distance. Usually, however, in addition, inward movements of eyeballs that are found in high grades of M, are absolutely restrained.

XCI. M as well as H are connected with strabismus. The condition is present when binocular vision, by reason of deviation of the visual lines, is suspended. Under such circumstances, the visual lines do not intersect at the point on which the attention is fixed ; and, in fact, on but one of the retinæ has the image of this point been placed in the fovea centralis of the yellow spot. The other central spot receives an image from another point.

XCII. M is connected with *divergent* strabismus. The rule is, that in high grades of M this variety of strabismus is *relative*, namely, that while the visual lines are correctly directed for seeing at a distance, *i. e.*, they are parallel, the maximum of convergence is insufficient for binocular near-vision.

XCIII. In *relative divergent strabismus*, convergence increases, close to its maximum, in proportion as an object approaches the eye. If the object remains at that distance, then the

one eye soon deviates to the temporal side; this taking place the moment that it is covered by the hand. Nevertheless, if the hand is taken away, the outward deviation generally remains, showing that the strong convergence was produced simply by an effort to continue binocular vision.

XCIV. The cause of relative divergent strabismus rests alone in the opposed convergence. The effort for coöperation of the retinæ, that is suspended in absolute strabismus, can here persist uninterruptedly.

XCV. As one of the results of the highest grades of M, the movement of the eye to the temporal side may also be restrained. For near-vision, there is a resultant *relative divergent strabismus;* for distant-vision, there is a *relative convergent strabismus;* while for intervening points, binocular vision has a restricted use.

XCVI. Divergent strabismus is *absolute* when binocular vision is not retained at any distance whatever. In one hundred cases of absolute divergent strabismus, M was found seventy times in one or both eyes in comparatively high degree. Statistics thus prove a relationship. The relative divergent strabismus, that is char-

acteristic of M, teaches that the connection is a causal one.

XCVII. If, therefore, the muscles are left undisturbed, then, as a rule, strabismus develops. A correct direction of the visual lines is only gotten by an effort to see similar objects directly with both eyes; that is, to place the images of the same object on both yellow spots. If one eye is blind, it in most instances, deviates to the temporal side.

XCVIII. Relative divergent strabismus produces dissimilar images on the two yellow spots during near-vision: through this, the need of similarity of images in general is diminished. A commencing deviation, arising from increased convergence, reaches at once a high degree. An exertion to converge is rather tedious because it brings with it an undue effort of accommodation, and therefore causes *r* to come nearer to the eye. Inaction and decreased energy of the internal rectus muscles are the results of this. Feeble resistance against double images and weakened power of the internal straight muscles thus coincide. When, during this condition, the action of these muscles is inadequate for seeing at a distance, then an absolute divergent strabismus is created. This condition develops itself the sooner: *a*,

because in the absence of proper V at a distance, double images are but slightly disturbing; *b*, by reason that when a parallelism of the visual lines requires an effort of the internal recti muscles, any exertion of accommodation coincides with it, and reduces V for distance; *c*, because the relationship existing between the visual axis and the line of vision in myopes (compare Paragraph LVI) is not favorable for obtaining a parallelism of the visual lines.

XCIX. By this means, a reason is offered for the origin of the greater number of cases of divergent strabismus. Cases coming into existence separately from the influence of M, are for the greater part the results of palsy or blindness of one eye (compare Paragraph XCVI). In injuries, contractures and complicated congenital anomalies, the cause is relatively seldom to be found.

C. With E in one eye and M in the fellow, and still more especially, with a low grade of M in the one and a high one in the other, divergent strabismus is the rule. Various forms can here be differentiated. In a general way, the interpretation of this rests in the facts that, in part, with the dissimilarity in the clearness and the size of the images, binocular

vision loses the greatest portion of its value; and that conversely, the convergence, which is already physically hindered, associates itself with an exertion for accommodation, and thus diminishes the visual acuity of the slightly myopic eye for distance.

In this form of strabismus, especially, many subjects are aware of the existent deviation, and are capable of temporarily neutralizing it at will.

CI. The results of H are asthenopia and convergent strabismus. The former is a quite ordinary symptom, while the latter is comparatively seldom seen.

CII. Asthenopia manifests itself as a fatigue-symptom that soon appears after near-vision. The eye is not apparently diseased, and it is not painful, even when it is exerted. Visual acuity and the ocular movements are both normal. Distant V is considered perfect, but reading, writing, etc., cause a sensation of tension over the eyes. Objects become indistinct. The patient rubs the forehead, closes his eyes, and recommences his work, only to sooner discontinue than before. Rest relieves the ocular fatigue, allowing a resumption of the work for a period of time that is commensurate with the amount of rest that has been taken.

CIII. Asthenopia has been confused with all manner of anomalies and has been especially sought for in the retina. By some it has been looked for in the organs of accommodation and by them has been ascribed to external conditions and undue efforts of the eyes. I have shown that asthenopia is not an accommodative anomaly, but that it is one of *refraction;* namely, a definite degree of H. Excessive action is consequently not the cause, but the essential inordinate exertion presents difficulties that expose the primarily existing anomaly.

CIV. The production of asthenopia from H is easy to understand. Visual acuity for distance requires an exertion of the accommodation to neutralize H. Begun thus with a deficiency, the accommodation soon evidences its inefficiency with increasing convergence. It is true, the eye accustoms itself to accommodate relatively very strongly with but slight convergence (compare Paragraphs XXXVI and XXXVII), but the positive part of $\frac{1}{A}$ is for moderate convergence very small in comparison with the negative portion; after slight fatigue it becomes equal to O; that is, p_2 withdraws to the position at which fine work has to be done. Should the object be removed to a greater distance, this change gives but a few moments' longer relief, for while at this point, $\frac{1}{A}$ is also almost

entirely negative, increasing fatigue makes p_2 follow closely to the greater distance. For p_2, all eyes are asthenopic, especially emmetropic ones.

CV. The stronger $\frac{1}{A}$ is, the higher in grade can H be without producing asthenopia. Whereas $\frac{1}{A}$ decreases with increasing years, asthenopia manifests itself so much the more tardily as H is low in degree. In $H < 0.75$, asthenopia is not to be found, or rather it merges into Pr.

CVI. The symptoms of asthenopia and Pr are unlike: Presbyopia entirely precludes acute vision, for instance, at twenty centimeters, but at a point that is somewhat farther removed, for example at forty centimeters, not even fatigue may be present; asthenopia frequently permits vision at a situation inside of twenty centimeters, but vision at a greater distance, for example, forty centimeters, is soon followed by fatigue.

CVII. To realize the difference between asthenopia and Pr, consideration should be given to the accompanying distinctive characteristics: 1. The loss of any fixed proportion of $\frac{1}{A}$ by fatigue has a more greatly increased influence on P and P_2 in young hypermetropic

subjects than it has in Pr, for the reason that in the latter, $\frac{1}{A}$ itself is much smaller. 2. At a greater distance than p_2, the positive part of $\frac{1}{A}$ increases in cases of Pr more quickly than it does in asthenopia. 3. The lines p_1, p_2 and p, and r, r_1 and r_2, designate the change of the dioptric system, and not the exercise of the muscular apparatus, of which effort it may be taken for granted that, *especially in Pr*, each addition produces a proportionately lessened change of the crystalline lens in direct relation as the bulk of the lens approaches its maximum. The result of this is that the positive part of $\frac{1}{A}$, particularly in Pr, expressed as a muscular effort, should be much greater than the negative portion.

CVIII. The real result of our acquaintanceship with the origin of asthenopia, is that various wearisome and troublesome kinds of treatment, succeeded by an acknowledgment of irremediability, have been abandoned for convex lenses of sufficient strengths to render neutral at least the manifest H, while each effort to methodically accustom the eyes to increasingly weaker lenses has been discontinued.

CIX. Convergent strabismus is, ordinarily, dependent on H. The *typical variety* is de-

cidedly thus connected. It generally appears from the fourth to the seventh years of age, and at times later, without any complaint in regard to double images, as a periodic monocular squint. At first, most frequently noticed only while gazing at near objects, followed later by its appearance while fixing upon more distant ones, it can be restrained in its development as long as it remains *inconstant* by the use of convex lenses. Soon, however, it passes into the permanent variety with a constant deviation that is generally confined to *one and the same eye* (strabismus simplex). In this stage, there is a shortening of the internal recti muscles, additional motility inwards, and lessened motion outwards in *both* eyes, this being associated with a decreased acuity of direct vision in the deviated eye as well as for indirect vision in the visual field that has remained common to both eyes. This lowering of V is gradually developed to such a degree that the deviated eye, during closure of its fellow, fails to fix on an object, but receives the image on a part of the retina that is situated to the inner side of the yellow spot, and thus actually distinguishes the object better than by direct vision, *i. e.*, by the receipt of the image in the yellow spot.

CX. The relationship between H and convergent strabismus is quite manifest: By

stronger convergence, H can be more easily overcome, and thus by an abandonment of binocular vision, the subject is able to see more sharply with one eye and to employ it more constantly for near-vision. Herein lies the reason why deviation at first occurs only during fixation, and this at an age when keener observation begins. Further, while at the time of deviation, attention is directed upon a specific object, yet it is not odd that neither its double-image nor the object which forms its image on the yellow spot of the deviating eye, should operate in a disturbing manner.

CXI. However natural it may be to thus explain convergent strabismus from a causative H, yet the condition is by no means an essential result thereof. The number of hypermetropes in whom strabismus is found is in reality relatively small. Manifestly, the origin is, as a rule, opposed by an inherent adherence to binocular vision.

CXII. The conditions that promote the formation of strabismus in H are of a twofold character: *a*, those which decrease the importance of binocular vision; *b*, those which make convergence easier.

CXIII. The usefulness of binocular vision is

decreased by diminished V in one eye, frequently as a consequence of acquired corneal spots; often also inborn, and in this case, not seldom dependent upon astigmatism.

CXIV. Convergence is rendered easier: 1. *Absolutely*, when the eyeballs offer but slight resistance to movements to the nasal sides, and the internal straight muscles possess an innate preponderance or are readily controlled by nerve influence; 2. *relatively*, when the line of vision forms a particularly broad angle with the axis of the cornea, and thus, for vision at a distance, a pronounced divergence of the axes of the cornea is required. (Actually, I have found the angle *a* greater in convergent strabismus than in the ordinary examples of H without squint.)

CXV. In developed convergent strabismus in which there is an effort for near-vision, the deviation is very slight, in spite of the fact that exertion for convergence is at this time undoubtedly much greater. Consequently, as soon as strabismus is found to be present, a definite amount of H does not so easily produce asthenopia. When by tenotomy, a proper position has been gotten, convergent strabismus often reappears from an exertion of accommodation. Under these new conditions,

the eyeball moves (sometimes arbitrarily) inwards under an impulse that as long as the deviation was present, gave but slight movement. A return of the strabismus is, in such cases only to be prevented by the employment of convex lenses that neutralize the H.

CXVI. Convergent strabismus may, by way of exception, depend upon a shortening of the muscles caused by paralysis of the antagonist, by wounds, and by contractures. It may be congenital, principally as a portion of a complicated anomaly. Lastly, it may be caused by a subconjunctival inflammation which has involved the muscle, this also in measure explaining the association between maculæ of the cornea and strabismus.

The essential points in the summary obtained are: Hypermetropia gives rise to an accommodative asthenopia, which can be counteracted by an actively produced convergent strabismus.

Myopia leads to muscular asthenopia which yields to a passively obtained divergent strabismus.

7. REGULAR ASTIGMATISM.

CXVII. The focal distance of the dioptric media of the eye is, in its various meridians, not precisely alike (*regular astigmatism*, As).

If by disregarding the distance k′ k″ and h′ h″, the dioptric system can be imaginarily reduced to one refracting surface, then this practically becomes the summit of an ellipsoid with three axes. The longest one is the visual axis, while the other two, which are perpendicular to one another, are situated in a vertical plane. The directions of the latter two are inconstant. Usually, however, the one deviates but slightly from the horizontal plane, while the other deviates but little from the vertical. In four-fifths of the cases, the latter is the shorter.

The meridians extending through the visual axis and one of the short axes, are known as the *chief meridians;* that of maximum of curvature is expressed by *m*, while that of minimum of curvature is designated as *m′*.

CXVIII. *Irregular* astigmatism may be traced to two causes: *a*, the curvature of the various meridians mutually differing, without absolutely corresponding to those of an ellipsoid with three axes; *b*, monochromatic homocentric rays, refracted in one and the same meridian, failing to remain homocentric.

CXIX. Irregular astigmatism depends almost always upon the crystalline lens, which is irregular in every respect. This may be inferred from personal observations. It is, however,

directly apparent from 1. monocular polyopia; 2. the rays showing points of light, and 3. the radiary lines of light seen in the entoptic spectrum (LISTING)—all of which disappear in aphakia (want of the crystalline lens). All of these appearances arise from the same causal factor and bear a direct relationship to irregular astigmatism.

CXX. In aphakia, only a definite amount of *regular* astigmatism remains, manifesting itself by a pure linear extension of a point of light in two opposite directions (limits of STURM'S focal interval), the light at the centre of the focal interval being seen as a round surface. In nine cases of aphakia with $V = 1$ or $V > 1$, m was about seven times vertical in position and but once absolutely horizontal, this being proven by the direction of the boundary lines of the focal space. These findings were proved by measurements of the corneal radius in the horizontal and the vertical meridians.

CXXI. The amount of regular *astigmatism*, As, is noted by $\frac{1}{l'}$, l' being the focal distance of a cylindrical lens which, added to m', should make the focal distance in m' equal to that of m. l' is expressed in meters.

CXXII. All eyes are astigmatic. In ordinary

degrees, this can be demonstrated in a well-acknowledged manner. In very slight degrees, and if there be much associated irregular A, its recognition is more difficult. It, however, can even then be made apparent by noting the visual changes produced by rotating weak cylindrical lenses (0.25 diopter cylinder or 0.50 diopter cylinder) before the eye, for by this plan, the combined value of the astigmatism of the lens and the eye is obtained in certain positions of the lens, while in the opposite position, the difference between the two is gotten.

CXXIII. As $<$ 0.75 diopters may be considered as normal; As $>$ 0.75 diopters is abnormal, because V in this condition is generally lowered and the use of cylindrical lenses is often of service. As of 6.00 diopters and 5.00 diopters is not rare. I have even seen As = 7.00 diopters.

CXXIV. The asymmetry just noted was discovered by THOMAS YOUNG in his own eyes; to a very abnormal degree it was first taken cognizance of by the astronomer AIRY, he finding it in his left eye. A few more instances have been met with in England. WHEWELL gave the condition the name 'astigmatism.' From the Continent of Europe but a single instance has been brought to our attention. This was

described by a clergyman living in Switzerland who determined its presence in his own eye. These cases were improperly considered as curiosities. It has appeared to me that out of every thirty or forty eyes one is affected with an abnormal degree of regular astigmatism. To this type belong most of the cases of congenitally defective vision.

CXXV. Just as for normal astigmatism, so likewise for the abnormal variety of the defect, is its seat, almost without exception, to be looked for *principally* in the cornea. This has been made apparent by comparing the degree of As with the variation in the radius of corneal curvature in the vertical and the horizontal meridians, or rather, approximatively in m and m'. Only when the radius of curvature is known in the principal corneal meridians, can the positive and the negative portions of the crystalline lens be *exactly* computed by comparison with the degree of As and with m and m' of the entire dioptric system.

CXXVI. Recently I have found a method to determine the principal corneal meridians and their radii of curvature. The three lights whose reflecting images, in imitation of BESSEL'S method, were employed by HELMHOLTZ for his studies with the ophthalmometer, are made

movable in a vertical plane around a point lying in the axis of the instrument which, during the examination, is arranged so as to coincide with the cornea. Without permitting any movement of the head, the radii of curvature in every meridian may accordingly be measured by rotating the lights, thus allowing the maximum and the minimum meridians to be determined.

CXXVII. Abnormal As. also corresponds with the normal variety in this, that, as a rule, m approaches the vertical meridian, and m' the horizontal one. In consequence, it is to be considered as a higher degree of the same form of asymmetry which is so characteristic of normal eyes.

CXXVIII. In order to ascertain the degree of As in diminished V., we should commence by endeavoring to determine the direction of the principal meridians. This may be accomplished in two ways: 1. From the directions of the lines under which a point of light is seen at the anterior and the posterior boundary of the focal interval. (These directions are only inaccurately indicated when there is relatively much associated As.) 2. By rotating a cylindrical lens that is approximately correct in front of the eye, by which the minimum, and especially,

the maximum degrees of V. can ordinarily be determined with exactness.

CXXIX. If the direction of the principal meridians is known, the most practical way is to estimate R in each of them.

This is accomplished by means of a narrow slit (by preference, a transparent strip situated between two blackened small glass plates that are turned toward one another). This is to be rotated before the eye, first in the direction of the one principal meridian, then in that of the other. In these two meridians, the strongest convex lens or the weakest concave one by which the best distant visual acuity can be gotten, is to be employed.

CXXX. By this means, it is determined whether E exists in one of the meridians, and to what amount ametropia is present in one or both of the meridians. The degree of As is obtained at the same time by the difference of refraction in the two meridians.

CXXXI. If E or H be present in one of the meridians, it is well, so as to obtain a very exact result, to previously paralyze the accommodation by means of atropine. Determinations of As for *p* by accommodation often produce variable results, because of the difference

of accommodative power of both meridians in two successive examinations. As a rule, however, the same eye appears to retain about the same degree of As during different accommodative conditions.

CXXXII. The astigmatic lens contrived by STOKES to determine the degree of astigmatism, allows, after correction of the astigmatism, the continuance of ametropia. It therefore cannot ordinarily be used to advantage unless myopia in *m* and *m'* (which is rarely so) be present, in which case, it may be employed for near reading-tests: It neither teaches (what is also necessary to know) the amount of ametropia in each of the principal meridians. In connection with spherical lenses, STOKES' method is, and ordinarily, cylindrical lenses are also, very valuable as control-tests.

CXXXIII. The method of AIRY, too, is merely of value in myopia with astigmatism, and in such cases in which there is but slight associated irregular astigmatism, gives alone fairly good answers. Modified for eyes that are not myopic, the plan becomes less useful.

CXXXIV. As. may be separated into several types: Myopic, Am; hypermetropic, Ah

(which is by far the most frequent); and *mixed* astigmatism, Ahm or Amh. *Am* is said to be *simple*, when E exists in m', and M on the other hand is in m. It is known as *compound* when M exists in m' as well as in m, consequently giving M + Am. Likewise, *Ah* is *simple*, with E in m and H in m'. It is *compound* when there is H in both m' and m, this being expressed as H + Ah. In *mixed As*, H is associated with m', and M with m. If M is predominating, the condition is known as Amh; if H is predominant, the condition is designated by Ahm.

CXXXV. As. is neutralized (although not with mathematical exactness) by cylindrical lenses. By this correction, V is bettered, and even at times, it is doubled or quadrupled.

In order to obtain $R = \infty$ in m and m' (and consequently, almost so in all meridians), are required:

1. Simple cylindrical lenses:

(*a*) Positive ones, usually biconvex in character, with parallel axes of both cylinders. Such lenses are expressed by $\frac{1}{L}$ C, in which, the focal distance L is indicated in meters. They are used for the correction of simple Ah.

(*b*) Negative ones, ordinarily biconcave in type with parallel axes. These are designated

by $-\frac{1}{L}c$ and are used for the correction of simple Am.

2. Bicylindrical lenses, the one surface being concave and the other convex, with their axes situated at right angles to one another: $\frac{l}{L}c \ulcorner -\frac{l}{L}c$. They are employed for the correction of Amh and Ahm.

3. Sphero-cylindrical lenses, one surface being spherical and the other cylindrical. When both surfaces are convex, then they are expressed as $\frac{l}{L}s \supset \frac{l}{L}c$; when both are concave, they are designated by $-\frac{l}{L}s \supset -\frac{l}{L}c$: compound Ah and Am,—that is, in H + Ah and in M + Am. When they are employed in such cases they cause R to equal ∞. The M and H of these compound refractive conditions are corrected by the spherical surfaces, while the remaining Ah and Am are neutralized respectively by the convex and by the concave cylindrical surfaces.

The adaptation of the lenses for cases in which it is desirable to bring R to a determinate finite distance, is accomplished in accordance with definitely known rules, this being mostly done by alterations in the spherical surface.

CXXXVI. The symptoms of abnormal As. are: 1. Diminution of V (through a peculiar deformity of the images of the retina); sometimes to as much as one-fifth of normal.

2. Indifference to markedly dissimilar spherical lenses.

3. Broadened image of a point of light which is elongated in two opposite directions, this being obtained by holding different spherical lenses before the eye.

4. P and R quite different for lines in two opposite directions that correspond with *m* and *m'*.

5. Estimation of measurements in the said directions likewise variable, this being in measure due to a difference in the calculated size of the retinal images by reason of accommodation (because of the variability of position of *k''* in *m* and *m'*), and partly on account of irradiation from unstable and inexact accommodation.

6. V improved by gazing through a slit, especially when the positions of the slit are the same as the angles of *m* or *m'*.

7. The appearance of two blue edges and two vertically opposite red edges on an illuminated square, when a violet glass is held in front of the eye (this in consequence of achromatism).

CXXXVII. All these symptoms can be personally observed by holding a cylindrical lens before the eye, thus producing a fairly regular astigmatism.

CXXXVIII. By adequate study, As can be

determined objectively by a recognition of the difference in the effort of accommodation made, in order to sharply see ophthalmoscopically in the perpendicular image, vessels of the retina that are running off in an opposite direction. In this way, I am even enabled to decide very exactly in reference to the ametropia in two opposite meridians, and in consequence, the degree of As. The surface of the optic nerve head appears elliptically distorted, when, as a rule, it is round (Knapp). During examinations with the upright and the inverted image, it will be found that this distortion appears in opposite directions, this difference of shape proving, as confirmed by further examination, the existence of As (Schweigger).

CXXXIX. As. may also be recognized as the result of corneal diseases, but in such cases, it is usually associated with much irregular As. The same is the case when, through partial luxation, the crystalline lens attains an oblique position. If a portion of the lens disappears from the pupillary area, a high degree of irregular As. becomes one of the results.

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